AFRL-SN-RS-TR-1998-118
Final Technical Report
June 1998

SATURABLE ABSORBING QUANTUM WELLS AT 1.08 AND 1.55 MICRON WAVELENGTHS FOR MODE LOCKING OF SOLID STATE LASERS

Gary W. Wicks, Consultant

Gary W. Wicks

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AIR FORCE RESEARCH LABORATORY
SENSORS DIRECTORATE
ROME RESEARCH SITE
ROME, NEW YORK

This report has been reviewed by the Air Force Research Laboratory, Information Directorate, Public Affairs Office (IFOIPA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

AFRL-IF-RS-TR-1998-118 has been reviewed and is approved for publication.

APPROVED: Reinhard K. Erdmann
REINHARD ERDMANN
Project Engineer

FOR THE DIRECTOR: Robert G. Polce
ROBERT G. POLCE, Acting Chief
Rome Operations Office
Sensors Directorate

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1998

3. REPORT TYPE AND DATES COVERED
Final Jun 96 - Oct 96

4. TITLE AND SUBTITLE
SATURABLE ABSORBING QUANTUM WELLS AT 1.08 AND 1.55 MICRON WAVELENGTHS FOR MODE LOCKING OF SOLID STATE LASERS

5. FUNDING NUMBERS
C - F30602-96-C-0169
PE - 62702F
PR - 4600
TA - P5
WU - PN

6. AUTHOR(S)
Gary W. Wicks

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Gary W. Wicks, Consultant
49 Countenay Circle
Pittsford NY 14534

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/SNDP (Formerly Rome Laboratory)
25 Electronic Parkway
Rome NY 13441-4515

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-SN-RS-TR-1998-118

11. SUPPLEMENTARY NOTES
Air Force Research Laboratory Project Engineer: Reinhard Erdmann/SNDP/(315) 330-4455

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Multiple quantum well designs were fabricated and tested at 1.55 microns. A series of 17 MBE fabrications were completed with deposits of various A1 In As/Ga In As alloys deposited on Indium Phosphide substrates. The spectral absorbance band edge was characterized and data provided for each sample run. Several samples were specially reduced to minimal thickness and gold coated to minimize losses. The application tests for use as saturable absorber in erbium doped fiber laser systems were performed on selected samples by personnel at Rome Laboratory. Issues of consistent control and repeatability were also addressed.

14. SUBJECT TERMS
Multiple Quantum Well (MQW), Saturable Absorber, Modelocked Erbium Fiber Laser

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TABLE OF CONTENTS

INTRODUCTION	1
DESCRIPTION OF SAMPLES	1
TABLE 1. SUMMARY OF SAMPLES CONSTRUCTED FOR THIS PROJECT	2
TRANSMISSION SPECTRA	2
DISCUSSION OF DATA	3
CONCLUSIONS	4
SAMPLE 1628	5
SAMPLE 1629	6
SAMPLE 1630	7
SAMPLE 1641	8
SAMPLE 1642	9
SAMPLE 1643	10
SAMPLE 1649	11
SAMPLE 1650	12
SAMPLE 1664	13
SAMPLE 1669	14
SAMPLE 1678	15
SAMPLE 1942	16
SAMPLE 1943	17
SAMPLE 1944	18
SAMPLE 1945	19
SAMPLE 1947	20
SAMPLE 1948	21
SAMPLE 1442	22

Introduction

Saturable absorbers constructed of semiconductor quantum wells have been successfully employed by others in mode locking Ti:sapphire lasers. In these applications, the saturable absorbing quantum well sample is positioned inside the laser cavity and passively, *i.e.* without electrical or optical control, causes the laser to mode lock. In a previous contract, we began developing quantum wells for mode locking Er^{3+} fiber lasers in the $\lambda = 1.55$ µm range. An additional interest is the development of quantum wells for short wavelenths for use with Nd:YAG lasers

The present application requires saturable absorption near $\lambda \sim 1.55$ µm. A previous contract demonstrated the feasiblity of constructing these saturable absorbing quantum wells in $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ epitaxial layers grown on InP substrates. An aspect of the first contract that required attention is the non-reproducibility. One or two quantum well samples in that previous study functioned well in mode locking the Er^{3+} fiber laser, many similarly prepared samples did not work as well.

This project is a continuation of the study, begun in the earlier contract, of the construction and evaluation of $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ quantum well structures for mode locking of Er^{3+} fiber lasers. The effects of MBE growth conditions and the post-growth fabrication on the performance of the mode locking ability of the samples was investigated. The low intensity absorption spectra of the samples were measured. After measurement of their cw, linear optical properties samples were delivered to K. Teegarden / R. Erdmann / M. Hayduk of Rome Labs for mode locking evaluation in an Er^{3+} fiber laser.

Description of Samples

During the course of this project, a total of 17 molecular beam epitaxy (MBE) runs were made. The samples consisted of alternating $Al_{0.48}In_{0.52}As$ and $Ga_{0.47}In_{0.53}As$ layers on InP substrates; each layer was nominally 100 Å thick. In addition, 7 samples were thinned to less than 100 µm and gold coated (on the substrate side).

The samples are summarzied in table 1.

sample#	number of periods	growth temperature (°C)	FWHM pulse width (ps)	FWHM spectral width (nm)	notes
1628	50	450			
1629	50	300	31.2	0.2	
1630	50	150			
1641	50	450	35.4	0.22	
1642	50	400			
1643	50	425	25.4	0.34	
1649	50	350			
1650	50	325	23.7	0.3	
1664	50	325			n-substrate, p-cap
1669	50	325			unsuccessful growth
1678	50	325			n-substrate, p-cap
1942	25	425			
1943	25	425	35.4	0.2	
1944	25	425	17.4	0.3	
1945	25	425			
1947	50	425	19.1	0.26	
1948	75	425	23.2	0.19	
1442	50				gold coated
1643	50				gold coated
1650	50				gold coated
1945	25		10.8	0.51	gold coated
1947	50				gold coated
1947	50		8.2	0.72	gold coated
1948	75		7.4	1.07	gold coated

Table 1. Summary of samples constructed for this project

Transmission spectra

The cw linear optical transmission spectrum of the 17 of the samples were measured with a commercial spectrophotometer. These 17 transmission spectra are shown in figures 1 - 17.

Discussion of data

This project concentrated on investigating which sample parameters have the dominant effects on the operation of the mode locking fiber lasers. The mode locking characteristics that were examined most thoroughly were the pulse widths and spectral widths (measured by Rome Labs personnel, M. Hayduk and W. Kaechele).

effect of growth temperature

Initially it was thought that the carrier lifetime in the semiconductor material is an important parameter. The lifetime is affected by the number of non-radiative recombination centers (defects) that are grown into the material. This defect concentration is a strong function of growth temperature — lower growth temperatures produces higher defect concentrations and, thus, shorter lifetimes. As can be seen in Table 1, the correlation between growth temperature and the mode locking characterstics (pulse width and spectral width) are very weak. The conclusion is that the earlier idea about the importance of carrier lifetime is not entirely correct. There may be some weak correlation between growth temperature and mode locking characteristics, but the growth temperature is not the dominant consideration.

effect of the number of quantum wells in the sample

A second sample parameter that was examined is the number of quantum wells in the sample, or the total thickness of the absorbing material. Samples 1945, 1947 and 1948 were constructed for this examination. A weak dependence of the mode locking characteristics on the number of quantum wells was found. Fewer wells produce shorter pulses.

effect of the thickness of the sample (after polishing)

Prior to the end of the present project, the sample that produced the shortest mode locked pulses was a sample from the previous project, #1305. Many tries to reproduce the results of this sample failed. Recently it was discovered that sample #1305 was polished to a thickness of only 200 μm, whereas most of the other samples had thicknesses in the 350 - 400 μm range. This is a matter that should be further investigated, however we feel that it is likely that the thickness of the samples is more important than previously realized.

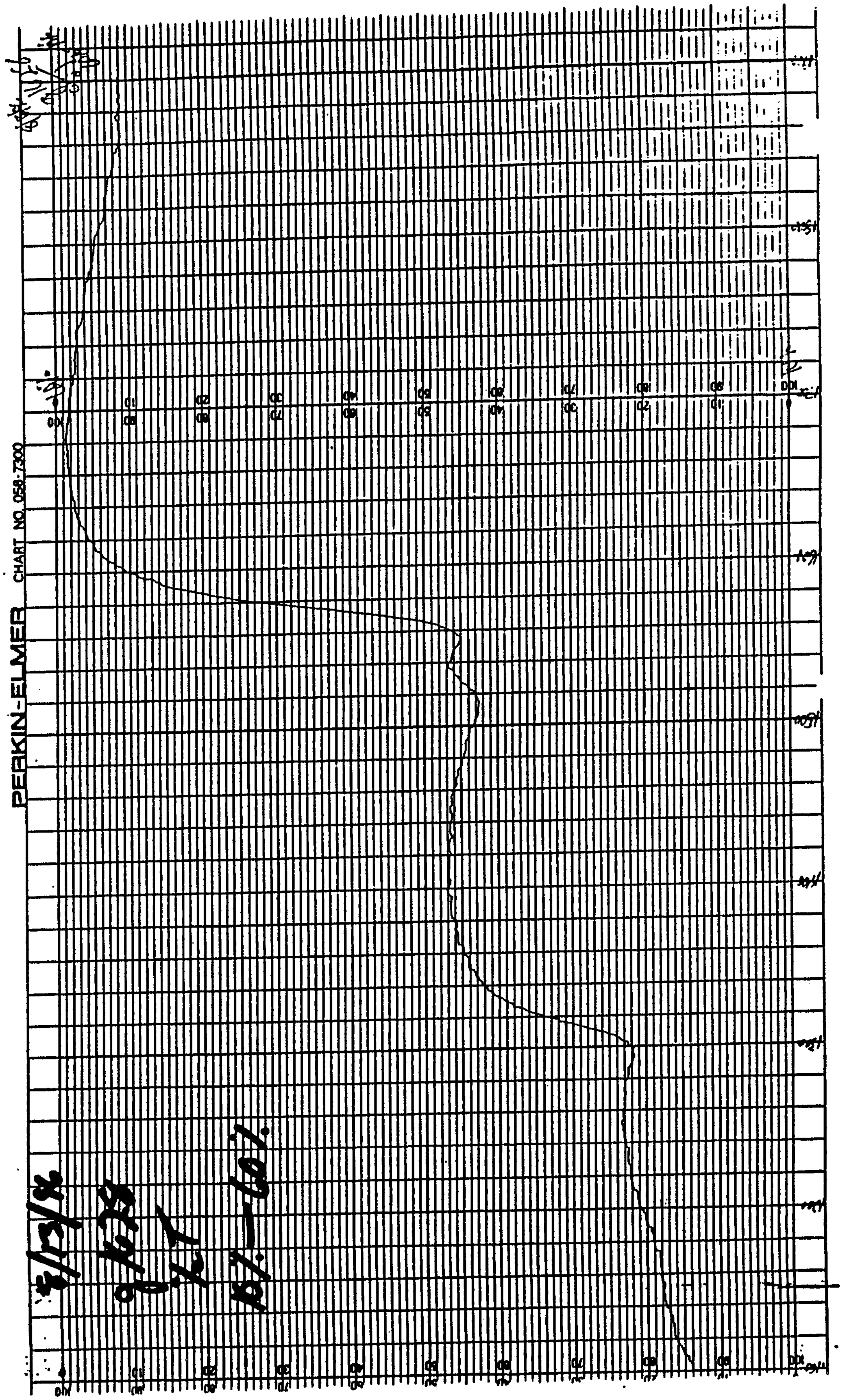
effect of thinning and gold coating

Discussions between the consultant, G. W. Wicks, and Rome Labs scientist, M. Hayduk, led to the idea that extreme thinning of the substrates combined with a high reflector on the substrate side would improve the coupling of the light back into the fiber, and thereby improve the mode locking characteristics. Several samples were thinned to less than 50 μm and gold coated on the substrate side. These samples proved to be the best mode lockers by far. See for example, sample #1948. Prior to thinning to 50 μm and gold coating, the sample produced 23 ps pulse widths; after the thinning and gold coating, the sample produced 7 ps pulse widths. Clearly, thinning and gold coating are sample fabrication parameters that are the the most important we have examined.

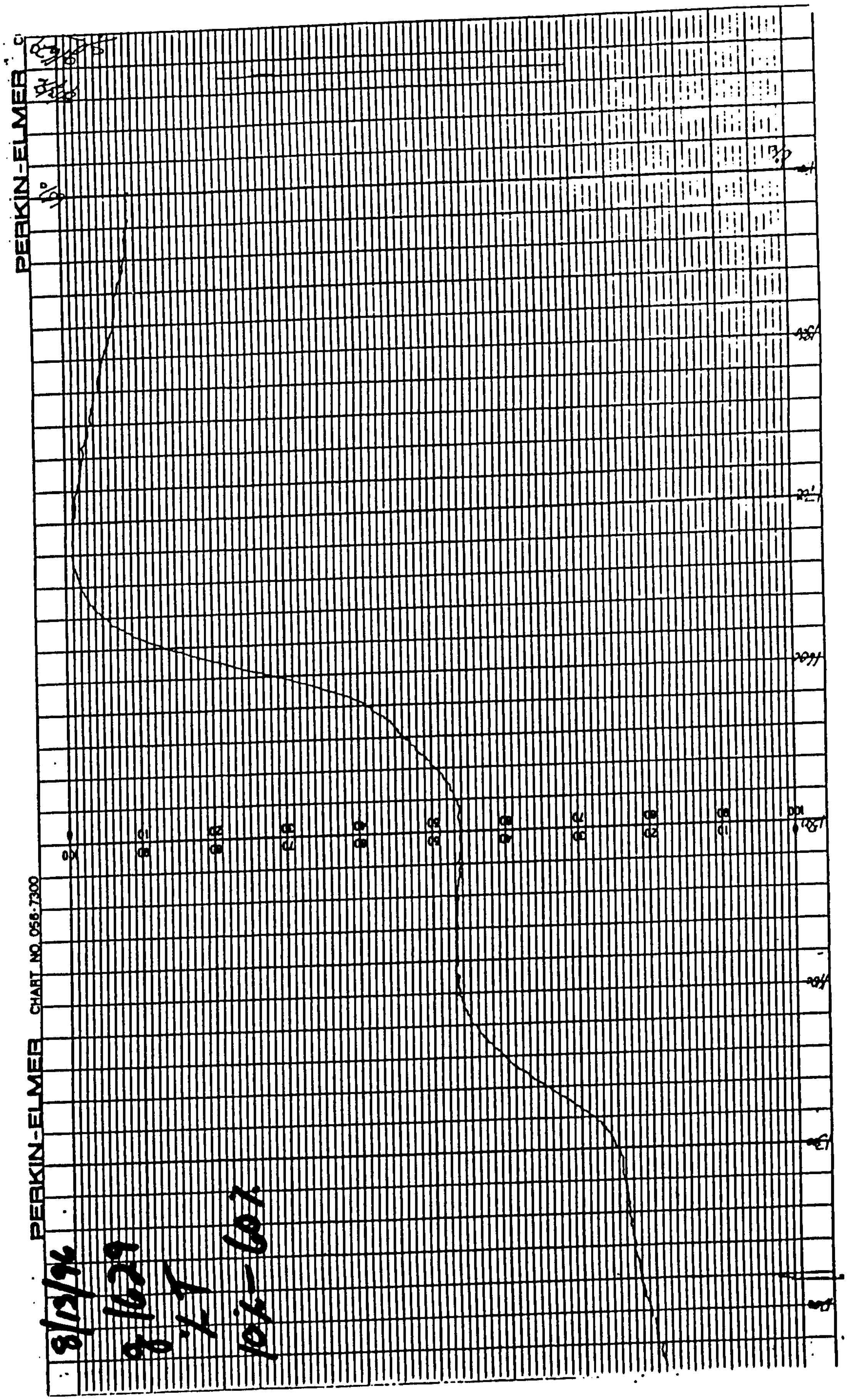
Conclusions

It has been demonstrated in this project that quantum well structures with saturable absorption near 1.55 μm can be very effective for mode locking Er^{3+} fiber lasers. The correlations between sample fabrication parameters and mode locking characteristics were examined. It was found that the fabrication parameters, which are most important in constructing samples for producing short pulse mode locking, are thinning to 50 μm or less and gold coating the substrate side.

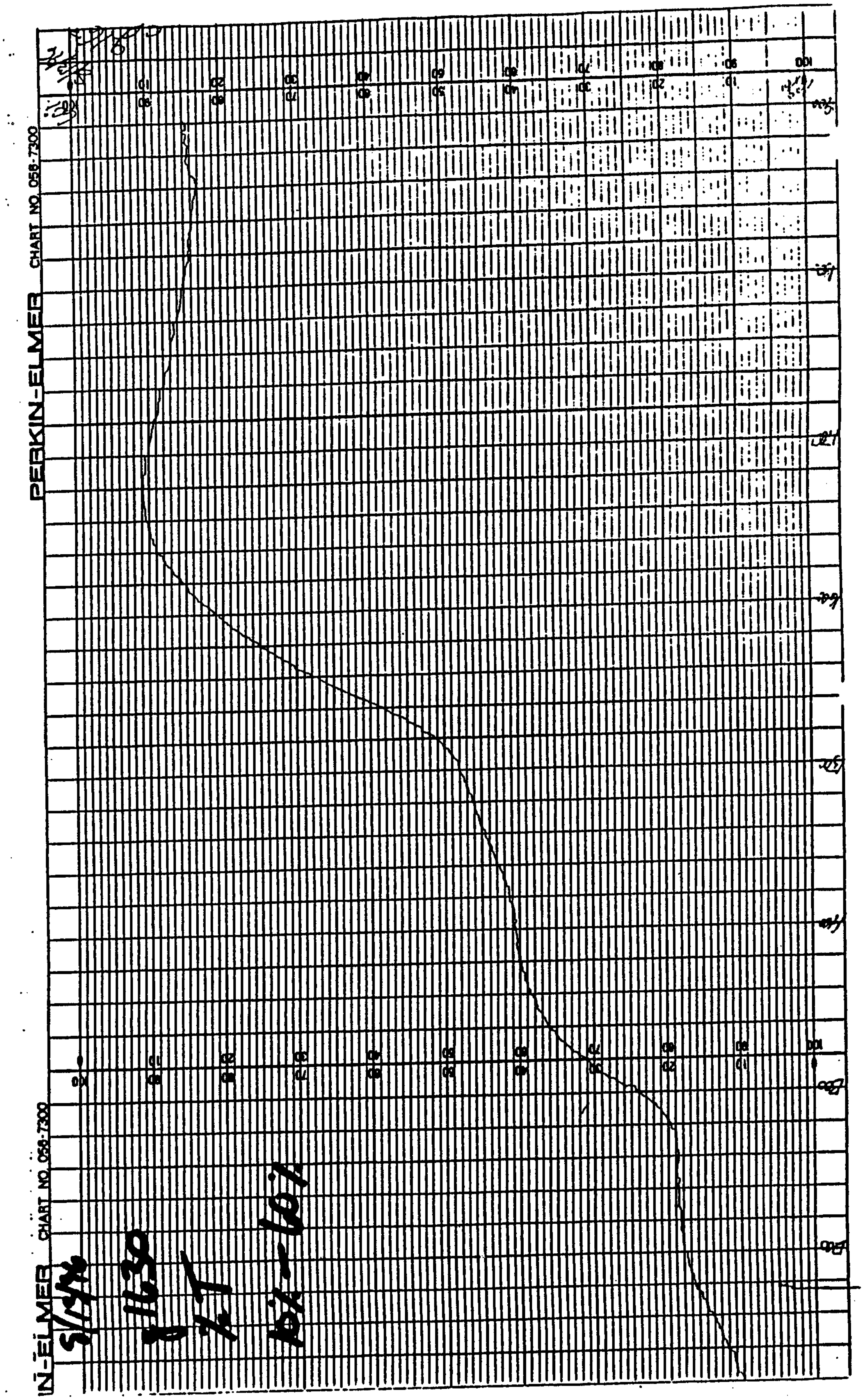
A potentially useful direction for future research in this area is the construction of electrically controlled saturable absorbers for active, rather than passive, mode locking. Such structures might be useful to reduce jitter in mode locking repetition rates.



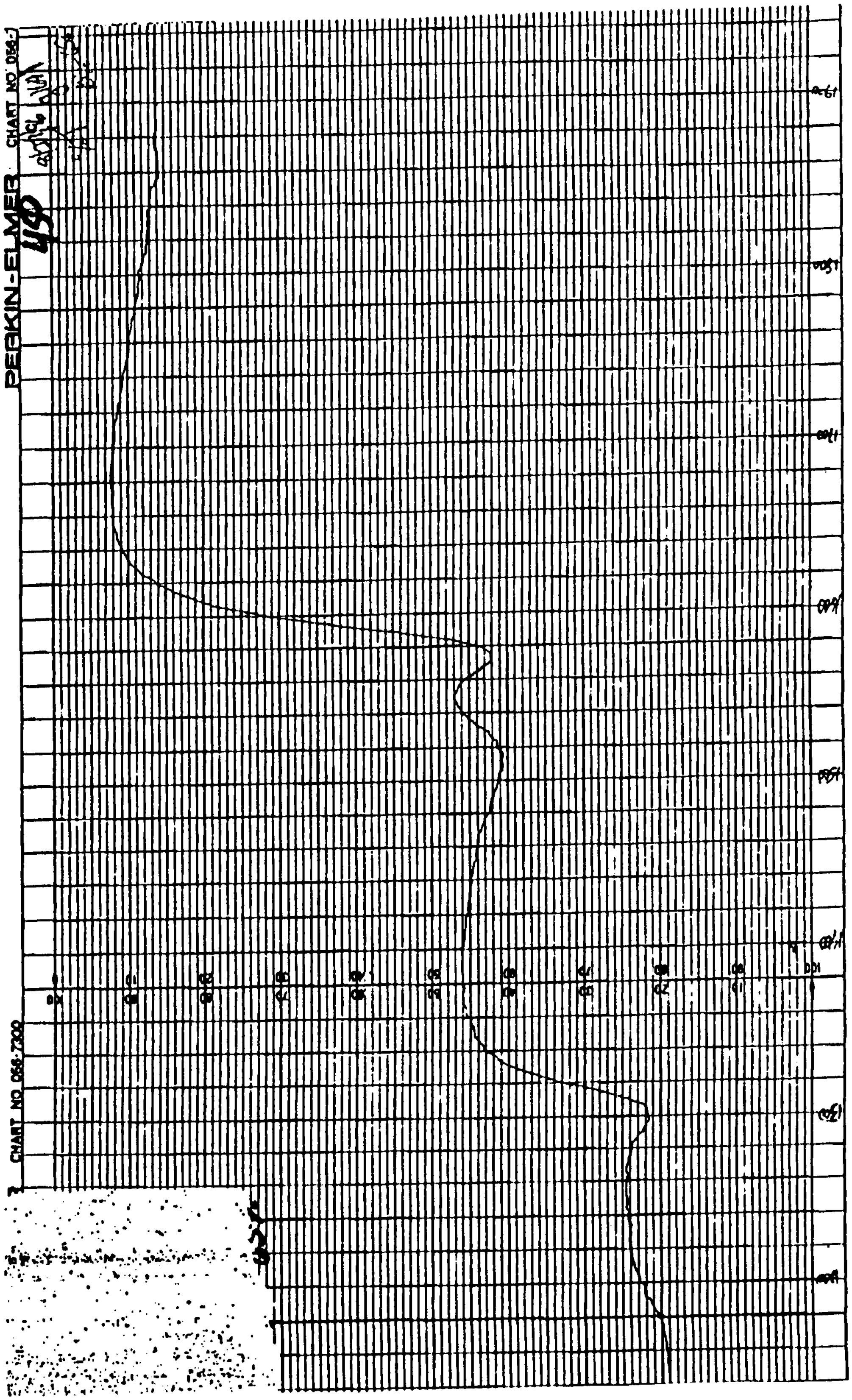
Sample 1628



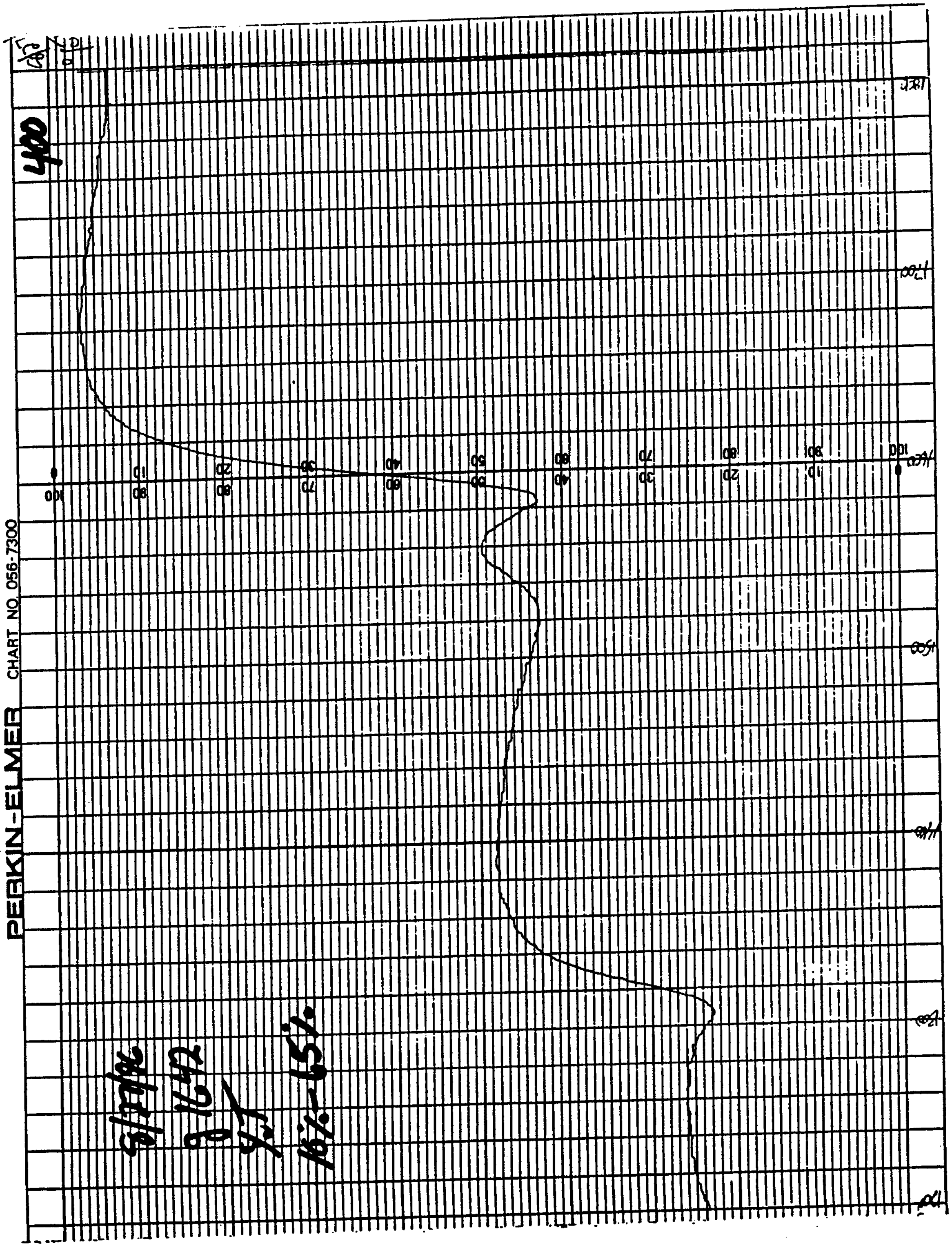
Sample 1629



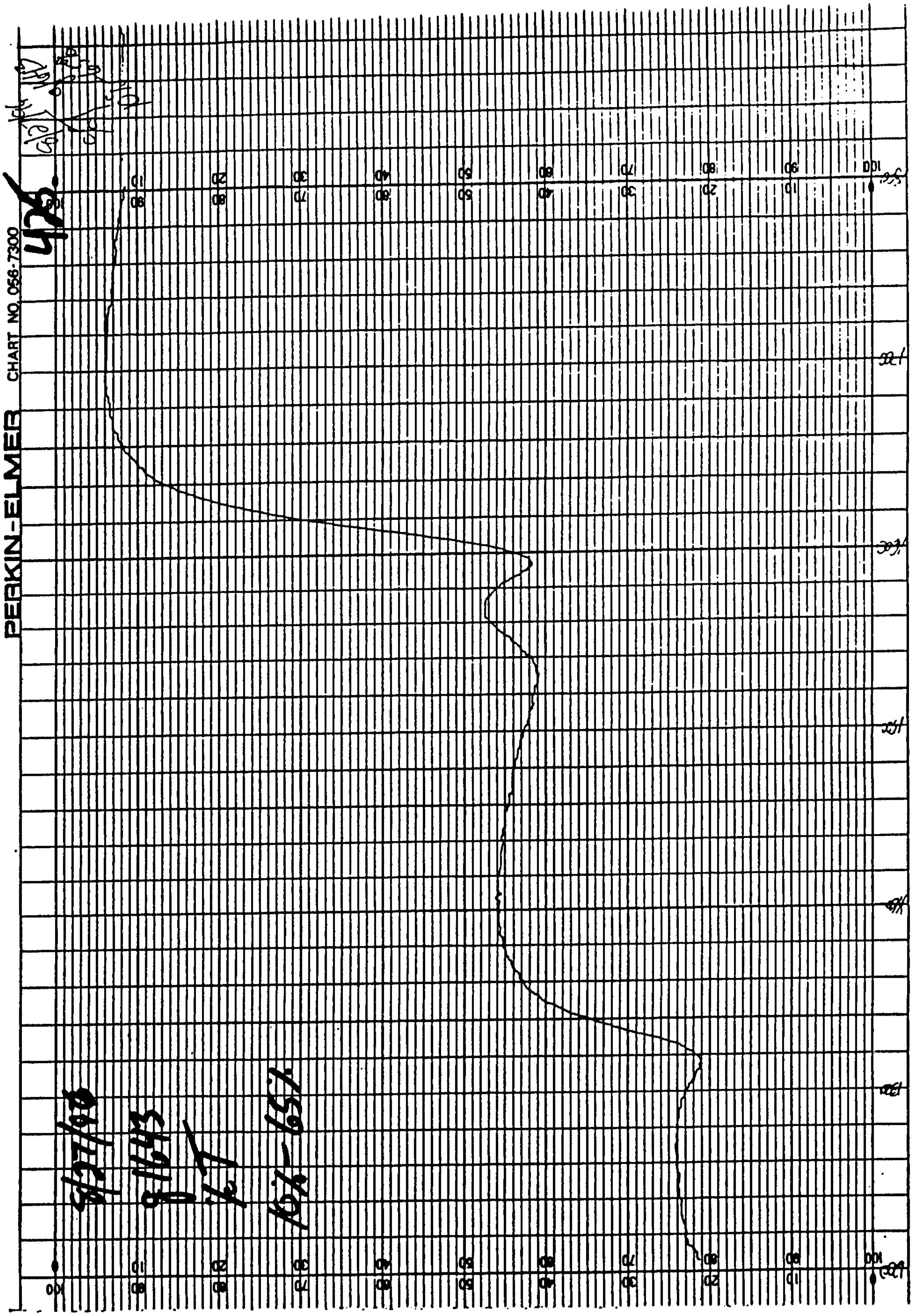
Sample 1630



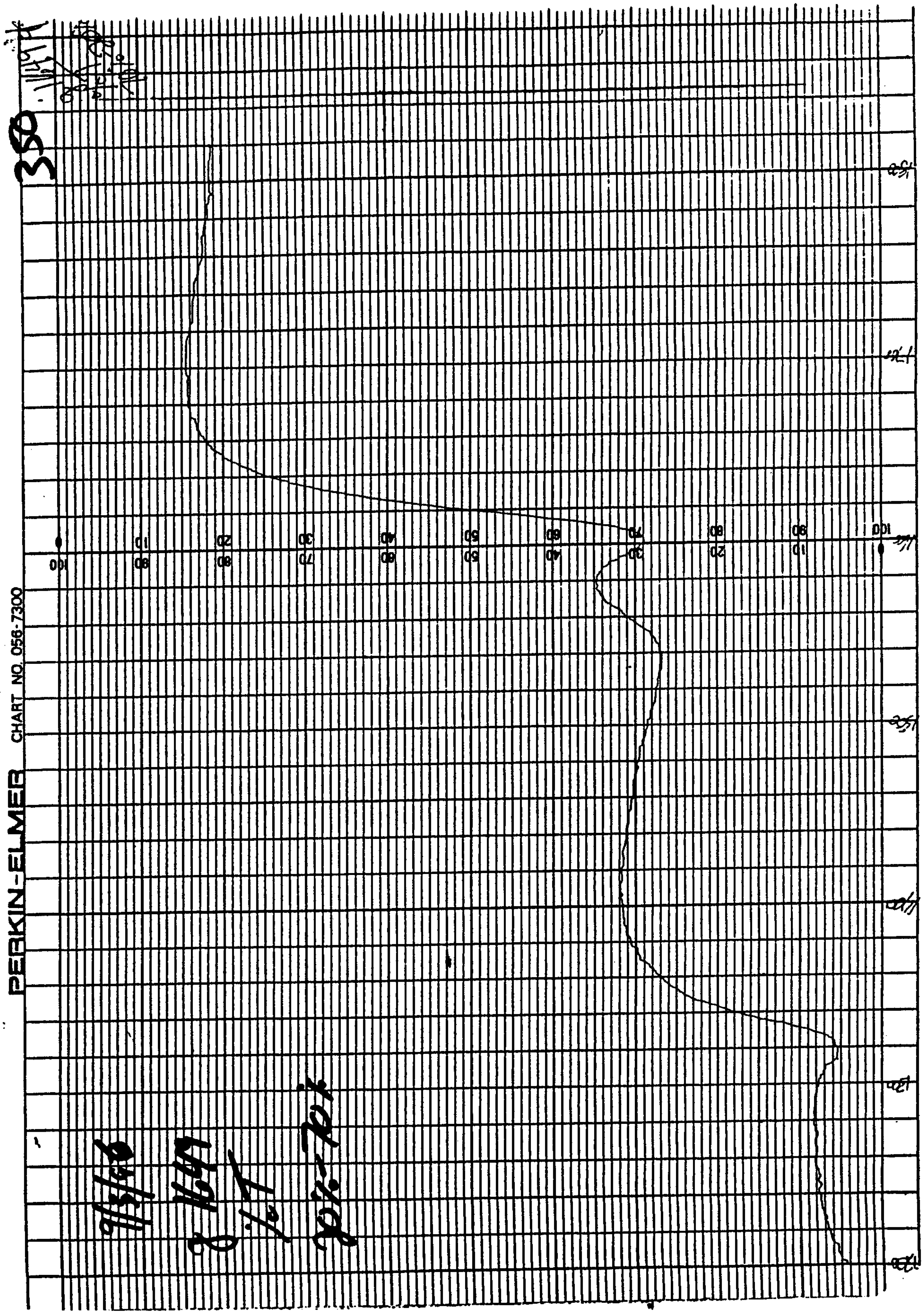
Sample 1641



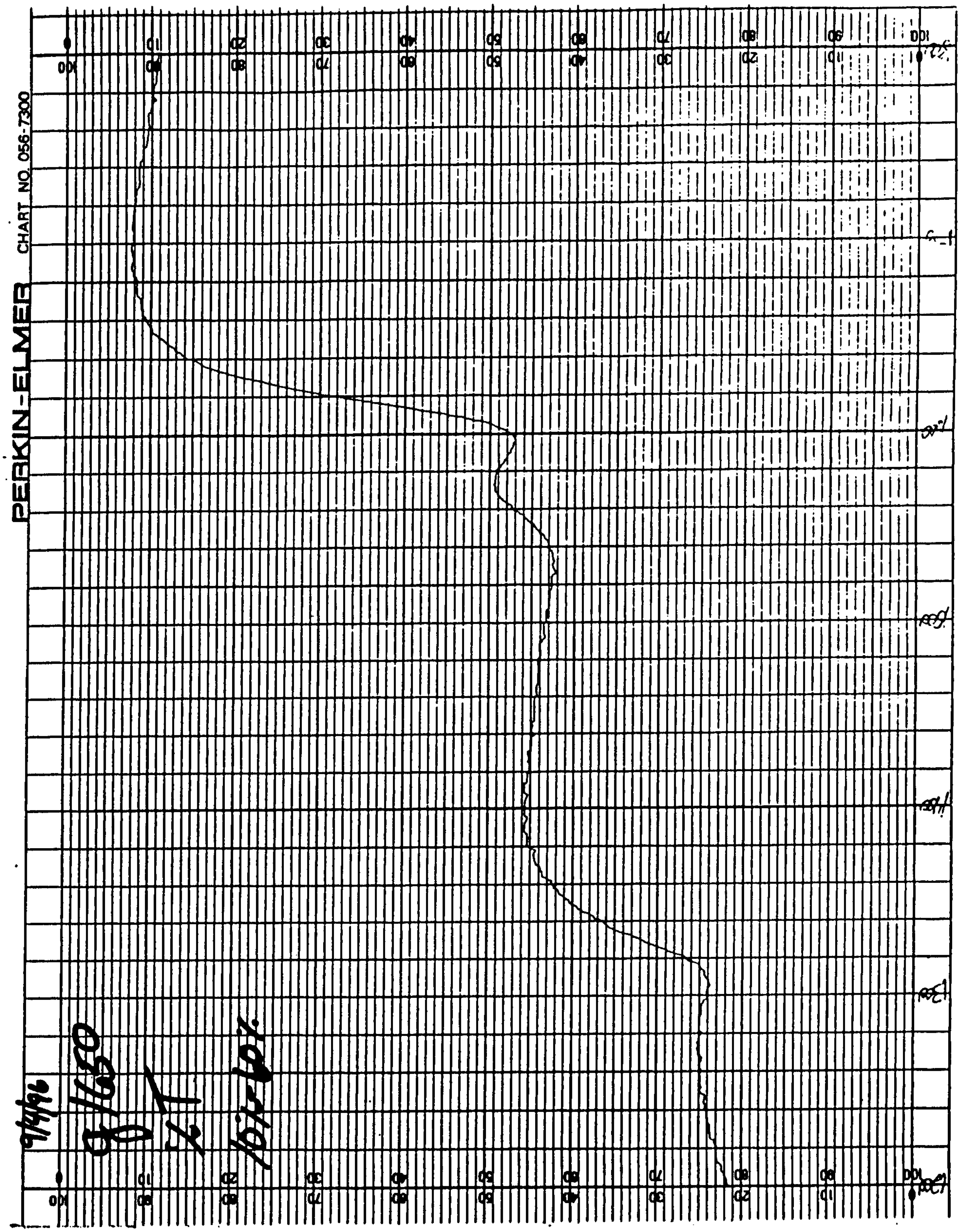
Sample 1642



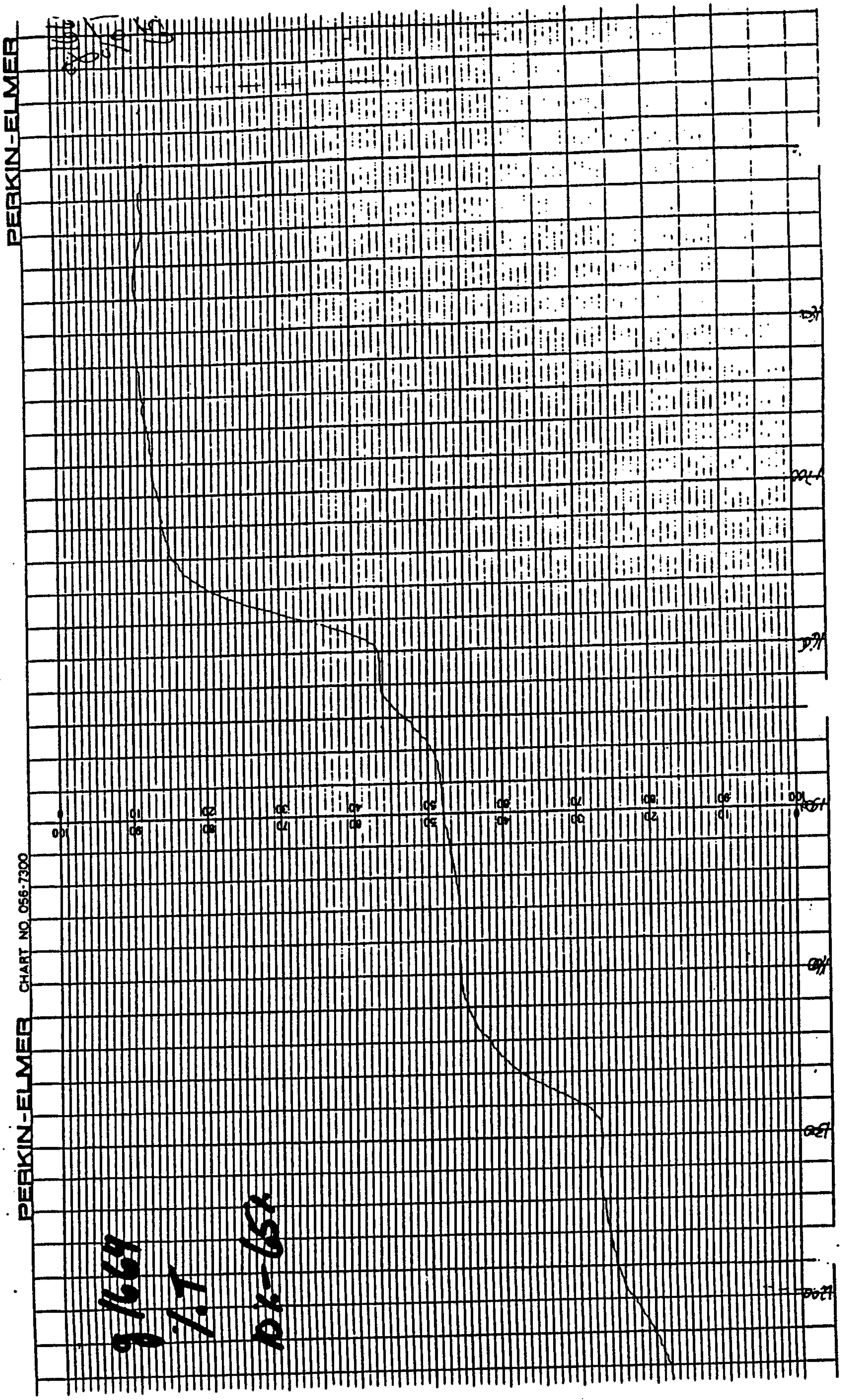
Sample 1643



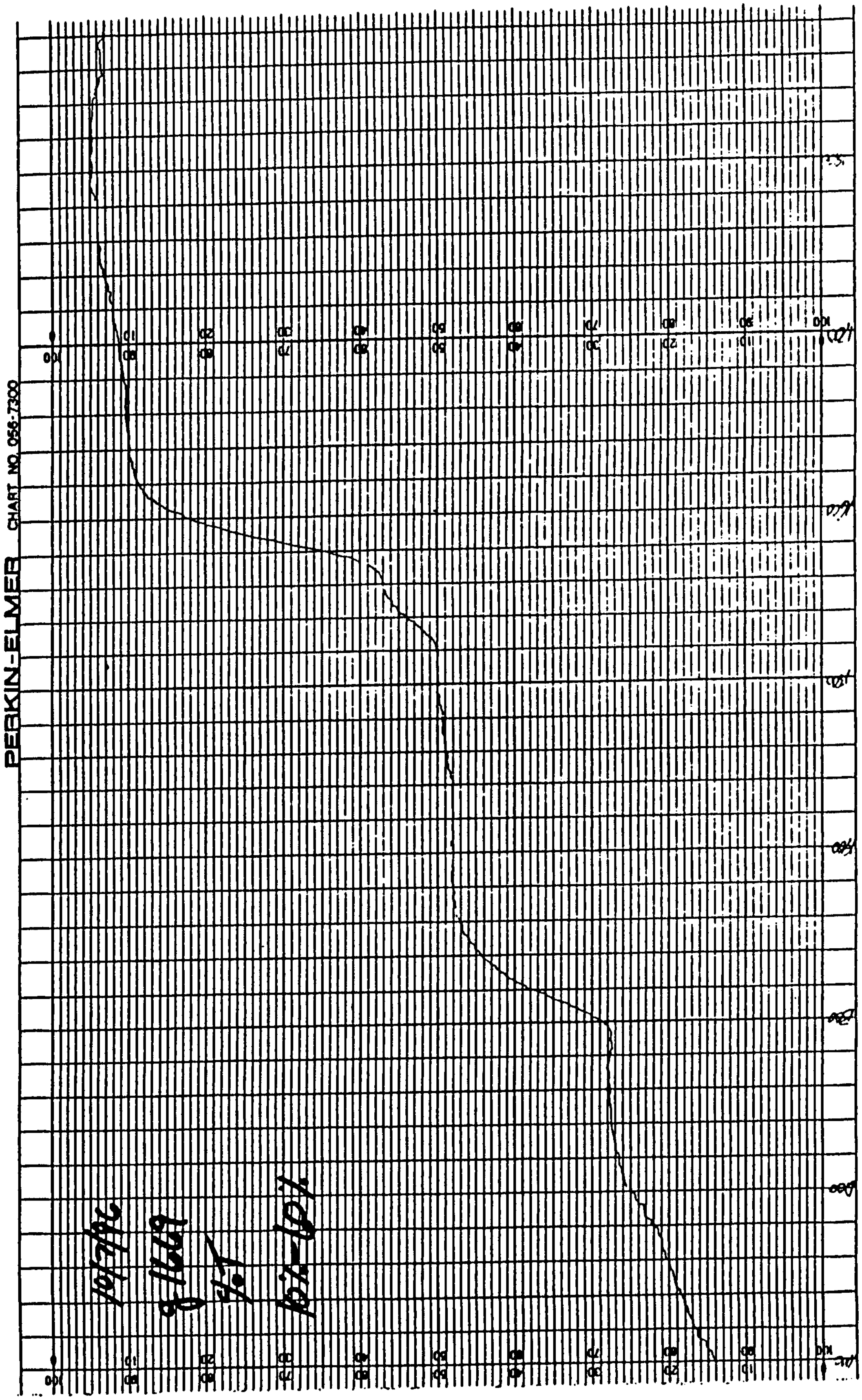
Sample 1649



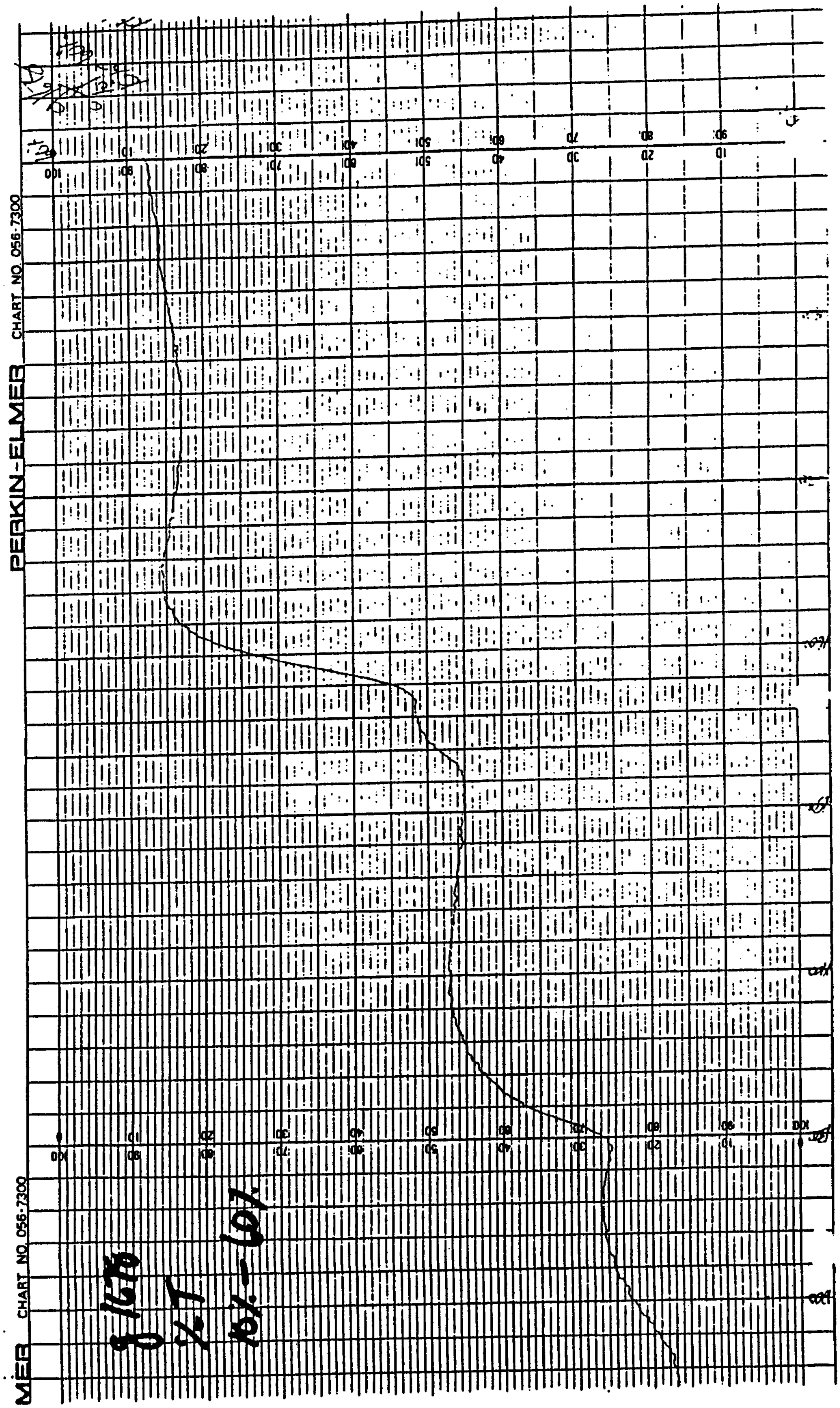
Sample 1650



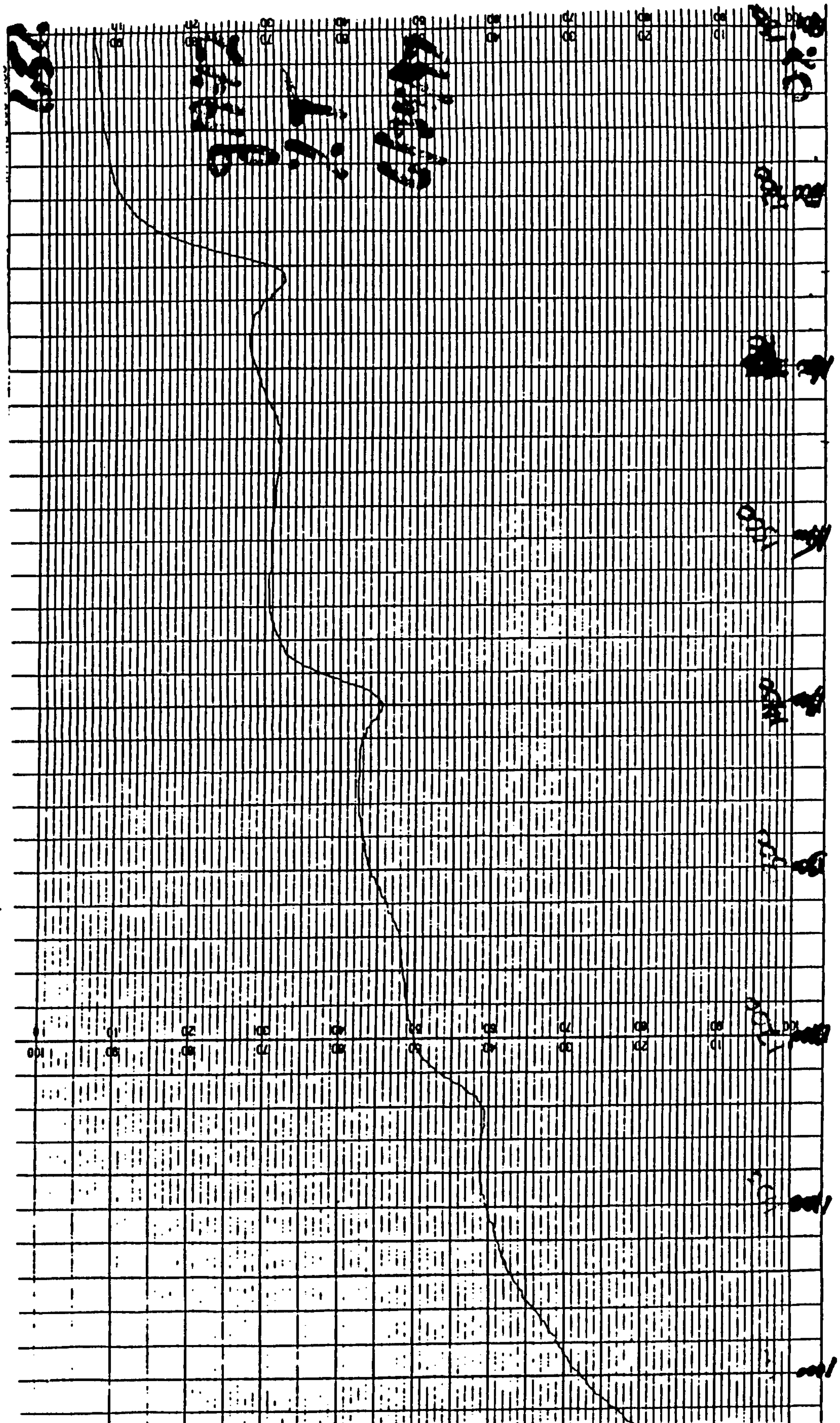
Sample 1664



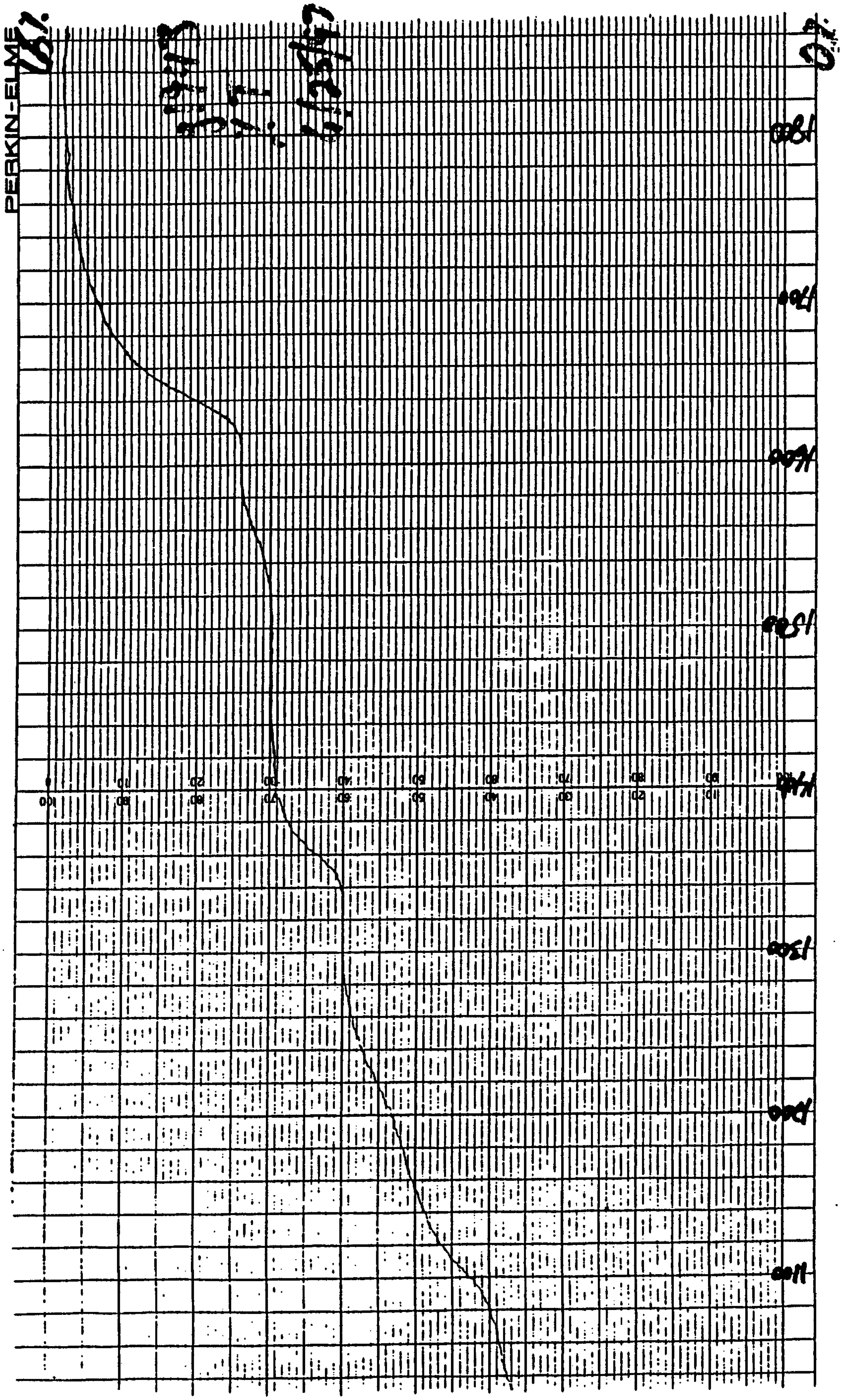
Sample 1669



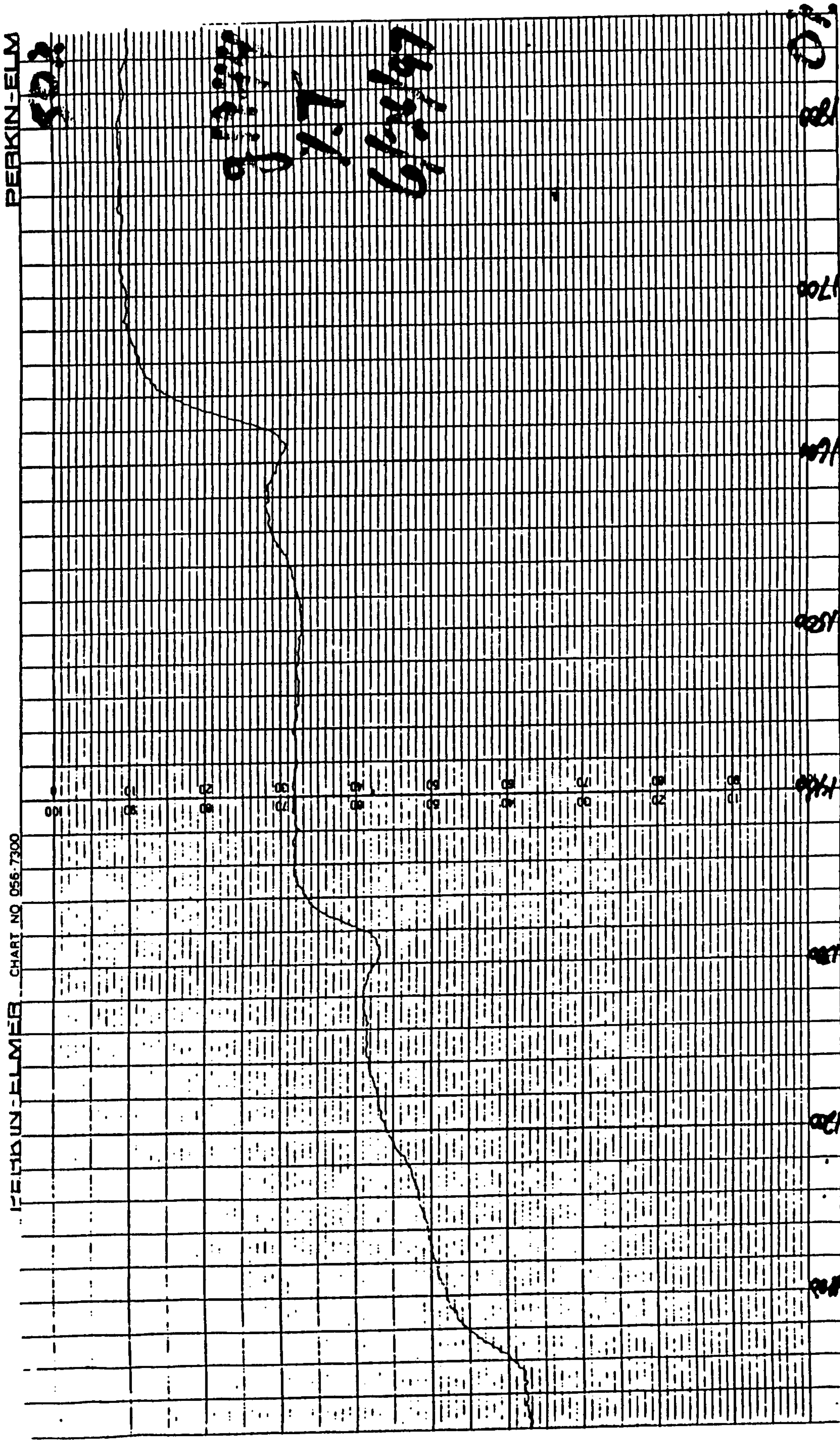
Sample 1678



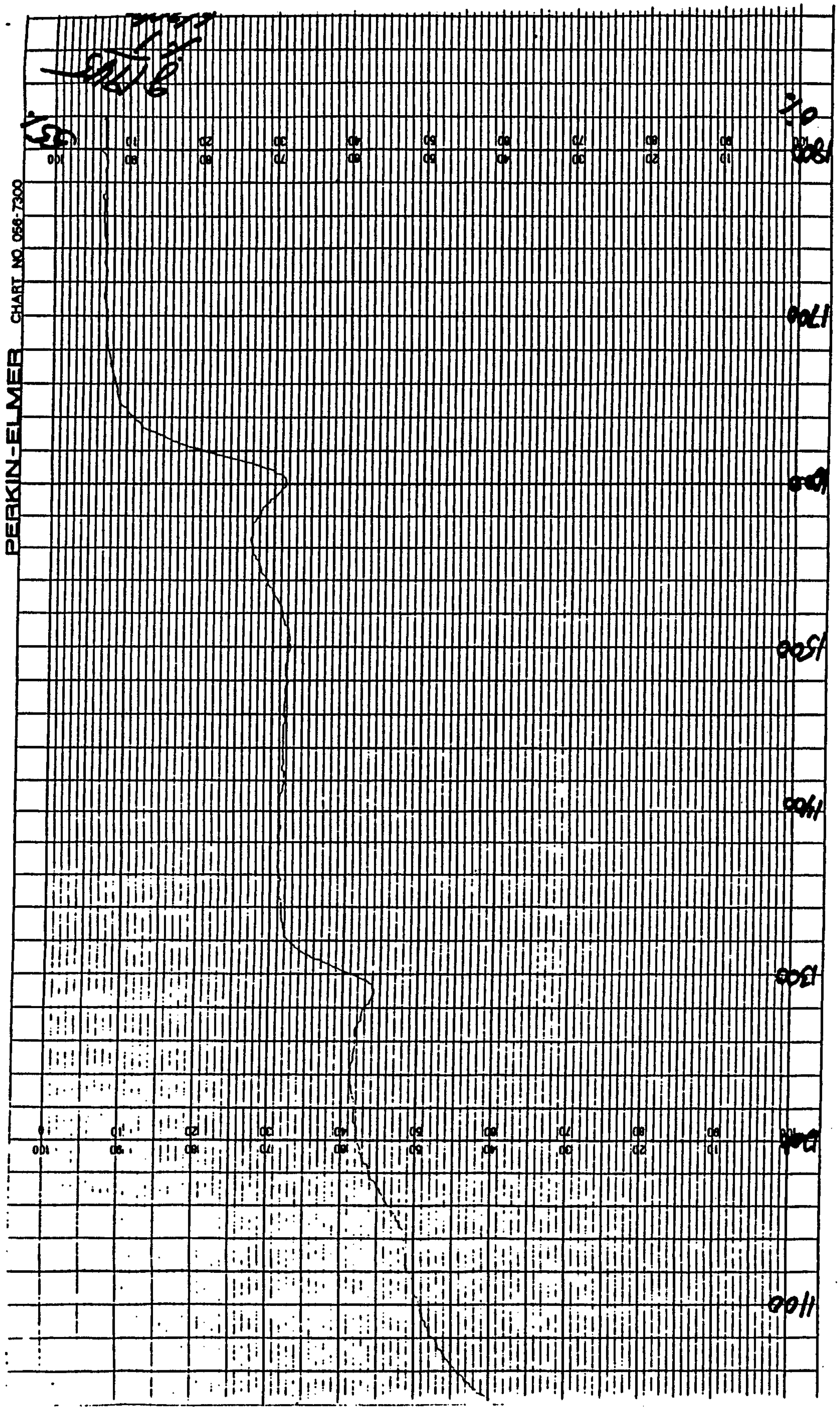
Sample 1942



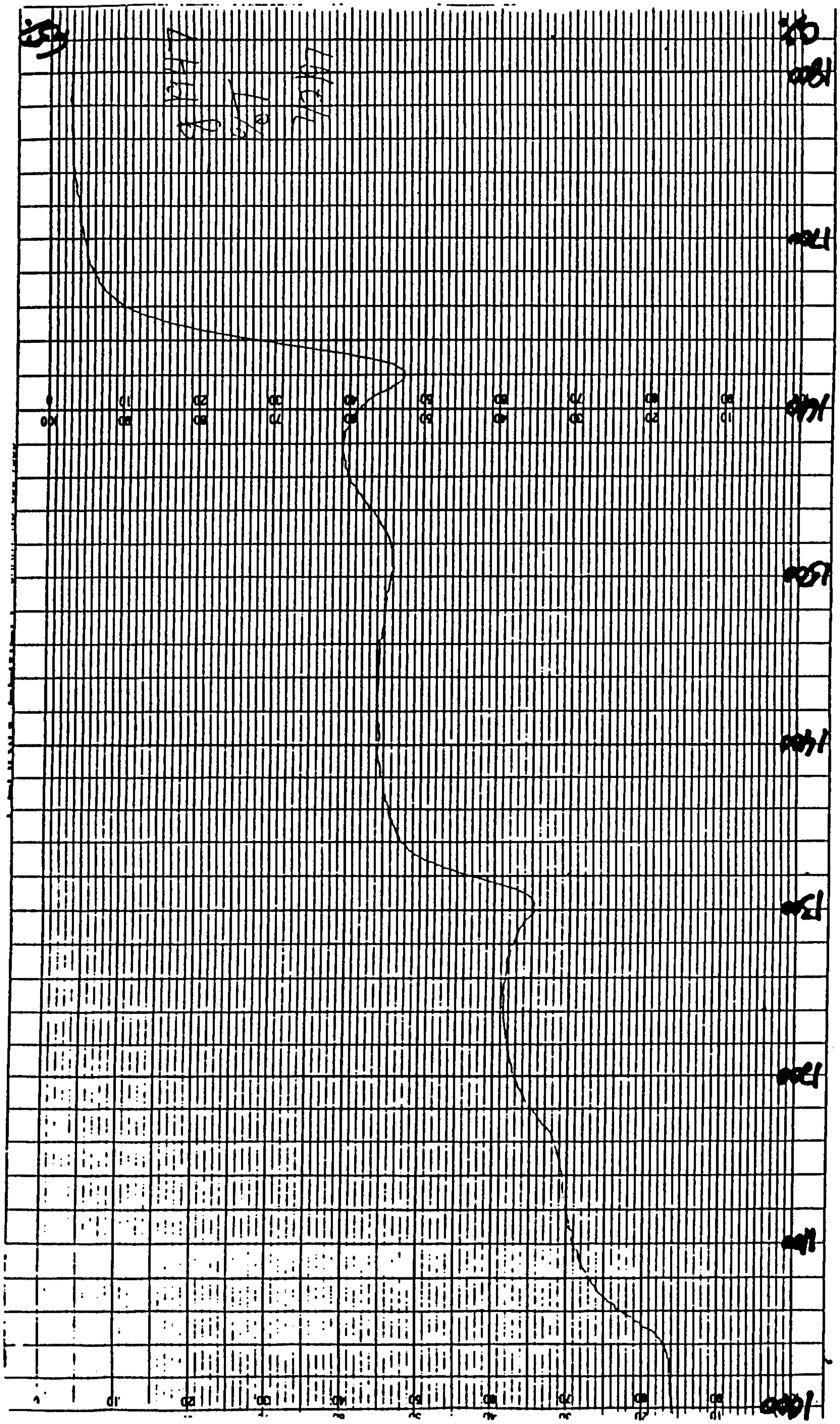
Sample 1943



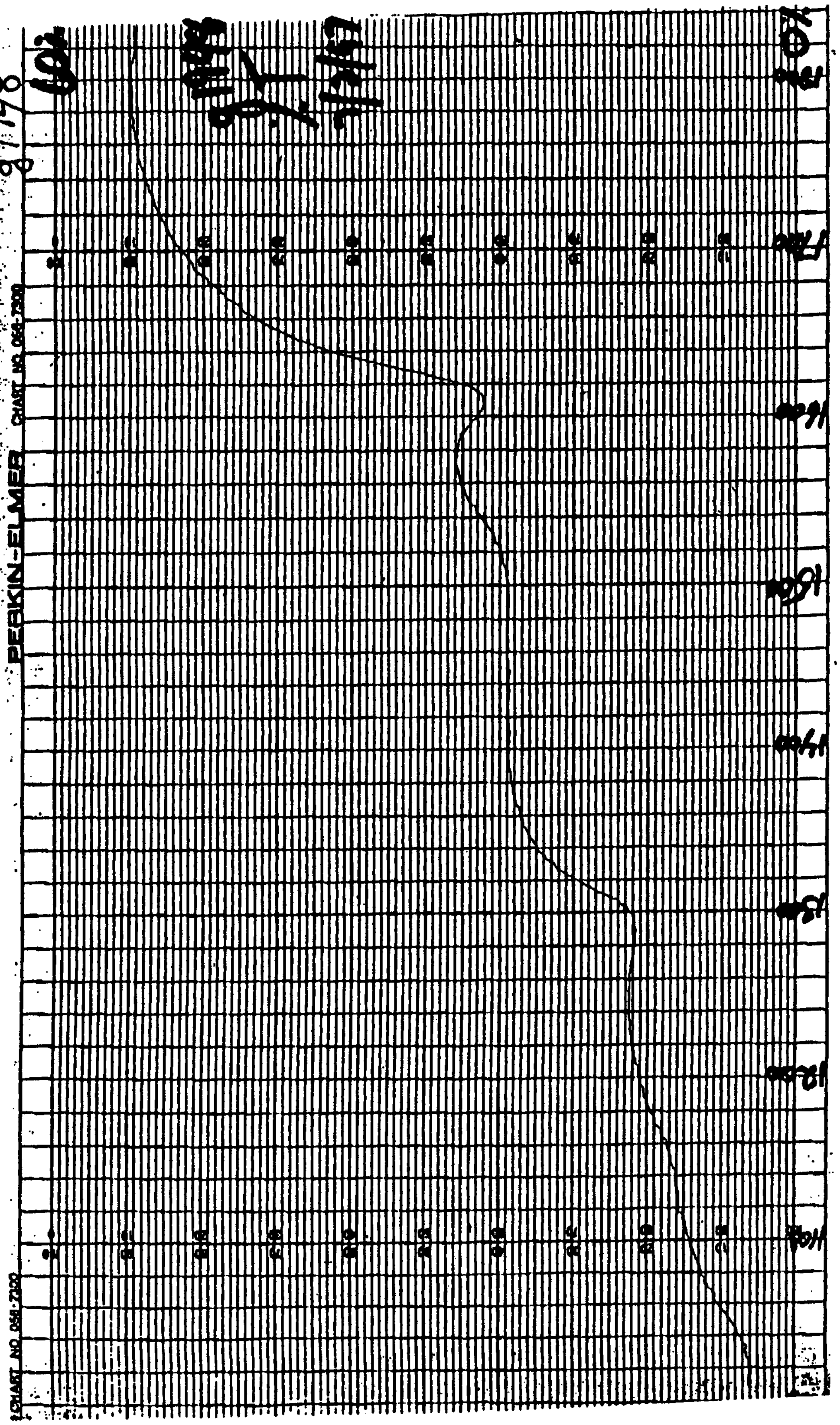
Sample 1944


PERKIN-ELMER
CHART NO. 056-7300
1800
1700
1600
1500
1400
1300
1200
1100

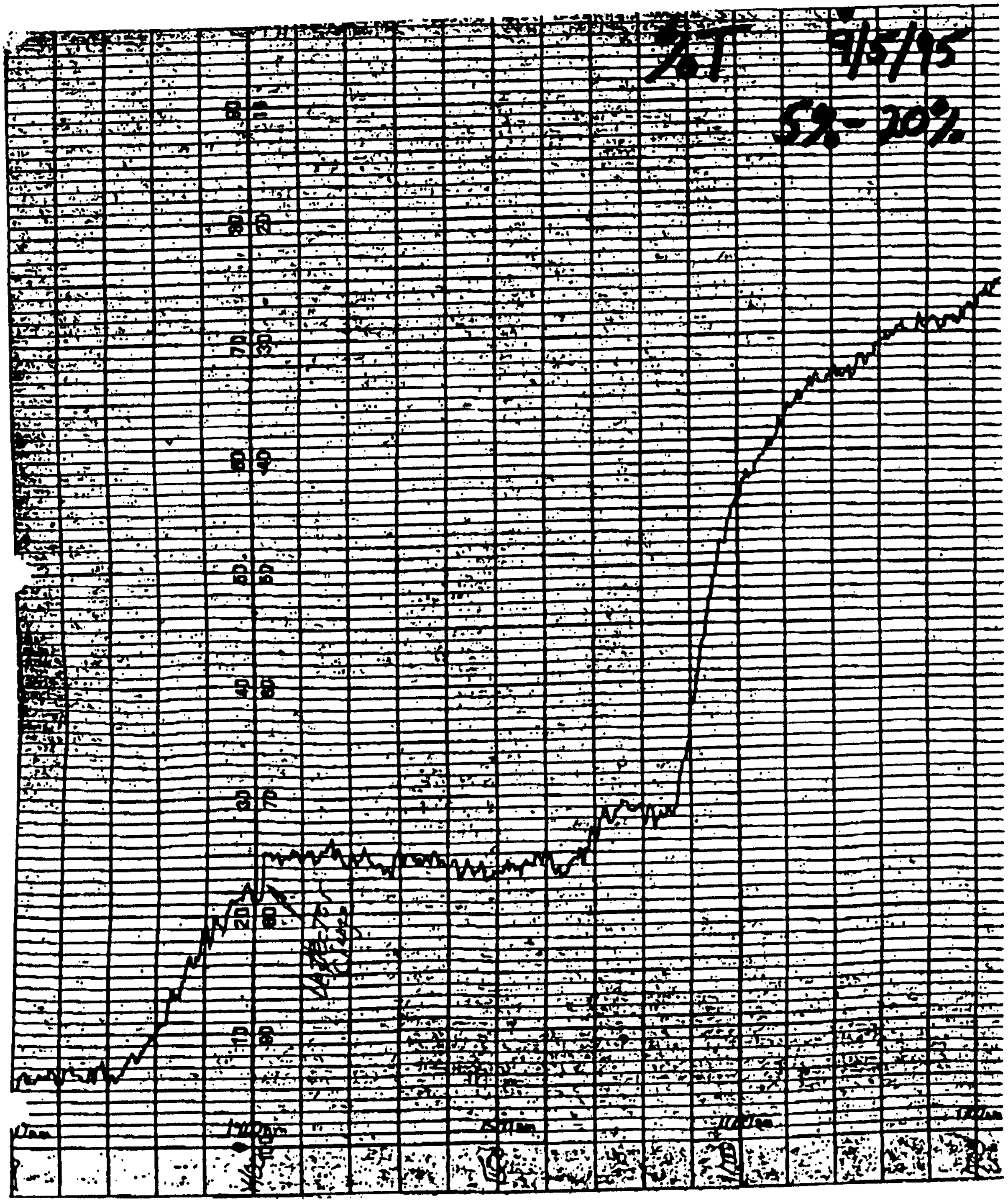
Sample 1945



Sample 1947



Sample 1948



Sample 1442